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Basis of the necessity of the thermal modelling and analysis of its problem

***Abstract**. This article describes the main destabilizing factors affecting to the electronic equipment. The basis describes the necessity of the thermal regime in the design of equipment using specialized software. The authors give the example of the calculation of the printed circuit assembly in the subsystem of the thermal modelling "ASONIKA-TM". The authors suggest to pay attention to the main problems of the thermal modelling and the possible ways of its solution.*

Streszczenie.** W artykule opisano główne czynniki destabilizujące, które oddziałują na sprzęt elektroniczny. Opisano konieczność stosowania reżimu termicznego w projektowaniu urządzeń wykorzystujących specjalistyczne oprogramowanie. Autorzy przedstawili przykłady obliczeń zespołu obwodów drukowanych w podsystemie termicznego modelowania "ASONIKA-TM". W publikacji autorzy zwracają uwagę na główne problemy modelowania termicznego oraz możliwe sposoby ich rozwiązania.**(Podstawy konieczności modelowania termicznego i analizy tego problemu).

Keywords: electronic equipment, modelling, the thermal process, destabilizing factor, printed circuit assembly.
Słowa kluczowe: sprzęt elektroniczny, modelowanie, proces termiczny, czynnik destabilizujący, zespół obwodów drukowanych

Introduction

The modern radio-electrical equipment (REE) of the crucial use (civil or military) works in the conditions of the destabilizing factors, which can be divided into the internal and external factors. The external factors include the influence of the external environment (temperature, humidity, atmospheric pressure), the background of radiation, the electromagnetic fields and mechanical factors. The internal factors include the components of the generated heat based on the electronic components and the activity assembly of the equipment. Unlike the internal, the external destabilizing factors influence to the REE, and even switch off state.

Temperature

REE consist of the blocks, each of can include several printed circuit assemblies (PCA). In turn, each PCA includes tens or hundreds of electronic components: resistors, capacitors, diodes, transistors, integrated circuits (IC), etc. The rapid development of the microelectronics industry promotes the annual increase of new electronic components, the growth of their functionality (microprocessors, FPGA). The consumption of the heat and the isolation the entire device are increased. Depending on the size of the efficiency of the device, the part of the electrical power is useful, but another part of the electrical power leaves in the form of heat into environment. The balance of the thermal energy is expressed by the equation:

$$E_{full} = E_{useful} + E_{dis} + E_{heat} \tag{1}$$

where: E_{full} – the energy supplied to the device, E_{useful} – useful energy, E_{dis} – dissipation of energy, E_{heat} – the energy consumed in heating device assemblies.

Thus, the efficiency is determined using the expression:

$$\eta = \frac{E_{useful}}{E_{full}} = \frac{E_{full} - E_{dis} - E_{heat}}{E_{full}} \tag{2}$$

As a rule, only 5-10% of the input energy is being transforming into energy of the useful signal, but another part of the energy is being scattering i.e. the electronic components and the hardware components are heated. The situation is aggravated if the ambient temperature reaches high values, making it difficult to heat and cool. Each electronic component has an operating temperature range, but if it falls outside the range, the characteristics of the elements will deteriorate and emerge from work. The failure of one component can lead to failure of the entire apparatus.

The temperature affects to the rate of chemical reactions. Thus, according to the Arrhenius equation, the chemical reaction rate constant depends on the temperature in the following manner [1]:

$$k = A \cdot exp(-\frac{E_a}{RT}) \tag{3}$$

where: A – the constant characterizing the frequency of collisions of the reacting molecules of a substance, E_a – the activation energy, R – the universal gas constant.

The characteristics of electronic components depend on the temperature. For example, the dependence of the resistor from the temperature is determined the following expression:

$$R = R_0 \cdot (1 + \alpha \cdot \Delta T) \tag{4}$$

where: R_0 – the resistance under normal condition, ΔT – the change of the temperature, α – the temperature coefficient of resistance.

Direct diode current is determined by the equation:

$$I_D = I_S(exp(\frac{V_D}{mV_T}) - 1) \tag{5}$$

where: I_S – the revers current saturation, q – the electron charge module, T – the absolute temperature, V_T – the temperature potential, m – the emission coefficient, V_D – the forward voltage of the diode.

The equations 3-5 indicate a significant temperature effect on the characteristics of the electronic components and accordingly, the parameters of the apparatus as a whole. In all descriptions on electronic components we can find the depending on the temperature of some parameters. Therefore, the temperature is an important destabilizing factor, the effect of which on the REE must be assessed.

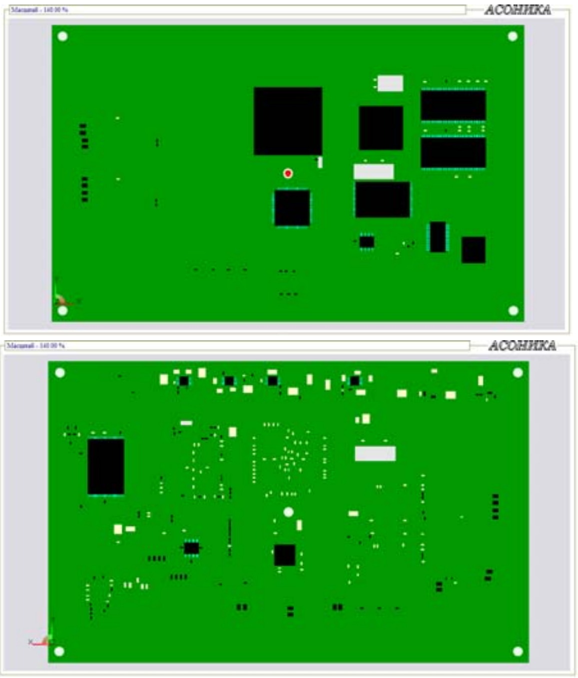
Modelling and CAD

The features of the effect of the temperature on the apparatus is requires the metering of the thermal regime in the early stages of the design. The thermal calculations can be made manually, but it will be necessary a lot of time for calculation. Therefore, it is preferable to use a computer-aided design (CAD) system, which can operate in automated mode the necessary calculations, saving our time and reducing the design process. Also, the use of CAD systems can reduce the number of possible design mistakes and can speed up the process of their elimination. The modelling can replace the field-testing line of the REE, and it reduces the time of the design and the expenses.

The modern market of the specialized software is variety. Among the foreign CAD systems for type design of equipment with modelling of the thermal effect, we should be note: ANSYS Icepak, MSC Nastran, Pro/Engineer Structural and Thermal Simulation, Creo Simulate, FLoTHERM, HyperLynx Thermal and others, which are described in books [1-3]. Among the domestic CAD systems, we can distinguish ASONIKA, which let us to analyze the thermal processes in blocks and PCA. As a foreign, CAD system, ASONIKA are constantly modified and taking into account the modern requirements: bug fixed, expands functionality, use new subsystems and etc.

Thermal calculation of the PCA

The thermal calculation of PCA was promoted into subsystem of the analysis of thermal conditions in the PCA ASONIKA-TM. The model of the researching PCA was created by us. We took into account the peculiarities of the construction PCA, see Figure 1.



a)

b)

Fig. 1. The 1st (a) and 2nd (b) sides of PCA

According to Fourier's law, the heat distribution by means of thermal conductivity strongly depends on the thermal conductivity of the material. The heat on the printed circuit board (PCB) is transmitted by means of the thermal conductivity on the PCB and copper. The coefficient of thermal conductivity of the two materials differs from each other in magnitude. Therefore, it is necessary to take into account the effective thermal conductivity of the PCB by the following expression:

$$\lambda_{eff} = \lambda_{pcb} \cdot \frac{\delta_{pcb}\lambda_{pcb}+K_{ff}\delta_c\lambda_c}{\delta_{pcb}\lambda_{pcb}} \tag{6}$$

where: λ_{pcb} – the coefficient of thermal conductivity of fiberglass, δ_{pcb} – the thickness of the fiberglass, λ_c – the coefficient of the thermal conductivity of the printed conductors, δ_c – the thickness of the printed conductors, K_{ff} – filling factor of the PCB conductors.

The filling factor is determined by the following equation:

$$K_{ff} = \frac{S_c}{S_{pcb}} \tag{7}$$

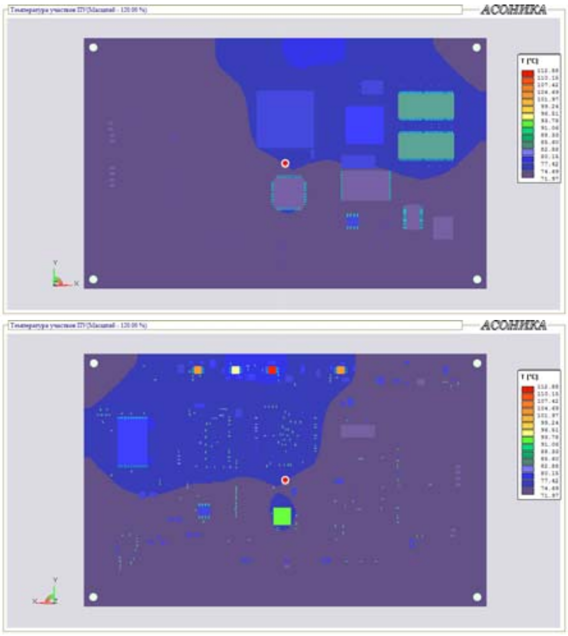
where: S_c – the area of the printed conductors, S_{pcb} – the PCB area.

It is assumed that the electronic unit, which contains a PCA, will operate at an ambient temperature from "-60˚C" till "+60˚C", the atmospheric pressure must be 760 mmHg. For the thermal calculation of the PCA is necessary to obtain thermal boundary conditions. For this electronic unit, which includes the reporting PCA, was simulated in the subsystem ASONIKA-T. Thermal boundary condition of the recording unit are:

1. Natural convection to environment and radiation from undeveloped flat surface on the neighbouring structural element for the first side of the PCA;
2. Natural convection to environment and radiation from undeveloped flat surface on the neighbouring structural element for the second side of the PCA.

Modelling of the electronic unit in the subsystem ASONIKA-T at "+60˚C" showed that for the first side air layer temperature is "+69.7˚C", and "+67.3˚C" for structural element; for the second side air layer temperature is "+75.9˚C" and "+77.2˚C" for structural element.

In Figure 2 show the temperature maps of PCA in stationary thermal conditions, where the ambient temperature is "+60˚C". Table 1 shows the temperature values for the problematic electronic components.



a)

b)

Fig. 2. Temperature map of the 1st (a) and 2nd (b) sides of PCA at ambient temperature is "+60˚C" and atmospheric pressure is 760 mmHg

Table 1. The map IC thermal conditions at ambient is “+60˚C” and atmospheric pressure is 760 mmHg

Designation IC	Side	IC temperature		Coefficient of thermal load [rel.u.]	Going beyond the permissible values [˚C]
		Settlement [˚C]	Maximum permissible [˚C]		
D13	2	93,37	85,00	1,10	8,37
D2	2	95,29	85,00	1,12	10,29
D4	2	105,38	85,00	1,24	20,38
D5	2	104,76	85,00	1,23	19,76
D7	2	112,88	85,00	1,33	27,88

The simulation results pooled in Table 1 and show that the ambient temperature is “+60˚C”, the atmospheric pressure must be 760 mmHg IC D2, D4, D5, D7, D13 - are overheated. The following measures should be taken to address these problems:

1. Use IC counter parts;
2. Use the same IC, but in another cases, are able to dissipate more heat output (have a lower thermal resistance);
3. IC use the same, but in another embodiment, a wider working temperature range;
4. Provide the data PCA IC cooling means (heatsinks, heat pipes, etc.);
5. Revise PCA topology (for example, change the location of the ICs, see the table above).

The example of modeling in a stationary thermal condition was considered above. There are some cases, when it is necessary to carry out the calculation of non-stationary. This is due to the fact that the parameters of the electronic components are depend on the temperature and operation of the device and can also vary with the temperature. It is important to know the temperature of the IC output time is a stationary mode in which its parameters are unchanged.

Figure 3 is a graph showing the temperature changes in D7 IC in time, resulting in a subsystem ASONIKA-TM in the range from 0 to 50 seconds.

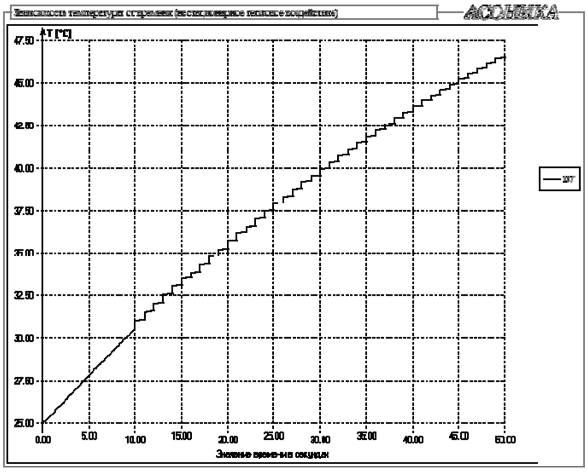


Fig. 3. The dependence of the temperature of IC D7 from the time at an ambient temperature is “+60˚C” and atmospheric pressure is 760 mmHg

Figure 3 shows that during the time interval from 0 to 50 with D7 IC the temperature increases from 25 to 46,5 ˚C (at initial temperature is 25 ˚C).

The problems arising during the thermal simulation

Modern CAD systems are developed constantly, but there are a lot of problems. The developers of REE are faced to these problems in the process of thermal calculation.

These include:

1. Inadequate attention, the accuracy and completeness of the database of materials and electronic components;
2. The difficulty in search of thermal parameters materials used in the design of electronics, materials and housings of electronic components;
3. Difficulties of calculating the correct values of heat release housings of electronic components.

Each of these issues increases the error of calculations, and can reduce their accuracy and reliability. Incorrect material database and the electronic components cannot create a complete and accurate thermal model design study. It is necessary to know for thermal modeling the heat in electronic components and assemblies of equipment. Otherwise, as a result of the simulation will be obtained incorrect results. It is desirable to find the ways of the solution these problems.

Ways of the solutions of these problems

The complete and accurate database is an essential attribute of qualitative and functional CAD system. It is necessary to compare the simulation results with the actual experiments to improve the quality of the database and, in case of discrepancies, we should to adjust the model.

Another problem is finding reliable values of thermal parameters of materials. It is possible to solve with the help of identification. According to articles [3,4] the identification is a word matching conforming between an object representation of a collection of experimental data and the properties of these characteristics, and the object model. We can determine the unknown thermal parameters of the materials. To solve the task of the identification by the main calculation we can determine the minimum of the objective function. The task of the identification is reduced to optimization. The decision is to make the objective function for mathematical model of the REE design and to find its minimum at given constraints on variable parameters: $\bar{X}_{MIN}<\bar{X}<\bar{X}_{MAX}$.

To identify the thermal parameters we must conduct an experiment with the design line REE, which is determined by its temperature, because there are special devices (thermocouples, pyrometers, thermo imager, etc.) with which you can easily determine the design temperature [5]. Therefore, the objective function must be expressed in terms of the relative change in the calculated and experimental temperatures.

Let $T^C=(T^C_1,\ T^C_2,\dots,T^C_N)$ - the vector of calculated temperatures; $T^{exp}=(T^{exp}_1,\ T^{exp}_2,\dots,T^{exp}_N)$ - is the vector of experimental temperatures; N - the amount of the calculated and experimental in this the equation:

$$F(\overline{X})=\sum_{i=1}^{N}\left(\frac{T_i^C-T_i^{\exp}}{T_i^{\exp}}\right)^2 \tag{8}$$

The criterion RMS provides fast convergence of the temperatures, but the calculated values are larger relative discrepancy with the experimental values.

According to articles [3, 4, 6] the most fruitful and promising methods of identification are using custom models. The method reduces to the scheme, it is shown in figure 4.

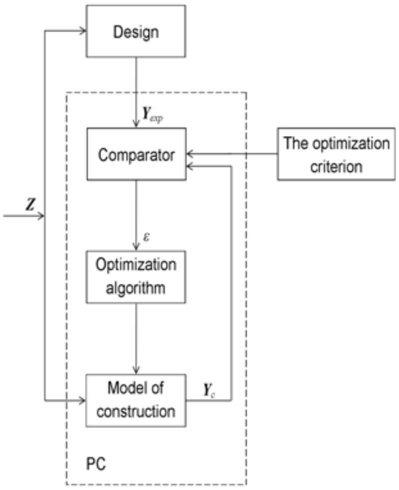


Fig.4. Identification of parameters with custom models

Figure 4 Z - the vector of input influence on the design of electronics; Y_{exp}, Y_c - the vector design reactions REE and its mathematical model, respectively; X - the vector domestic varying design parameters of REE, which is necessary to identify; $\varepsilon = | Y_{exp} - Y_c |$ - an error.

We can identify as one possible parameter of the material, as some parameters of the material. At the same time, there are various methods for finding the minimum target of the design function. See articles [7,8]. In solving of one dimension optimization problem is an acceptable method of golden section, and in solving the problem of multivariable optimization, we must use Nelder-Mead method.

To obtain the correct heat release enclosures values need to be embedded in the CAD modules which let us to conduct electrical modeling line, or to use the third-party specialized software: OrCAD, which is described in source [9], Multisim, etc. With the help of electrical simulation, you can get the power of the thermal emission housings of electronic components and functional assemblies of REE that are need to conduct the thermal calculations.

Conclusion

The paper presents the basis for metering of the temperature in the design of electronic devices. The example of the thermal simulation of the PCA in the subsystem ASONIKA-TM. The conclusions are made according to the results of the calculation. The modern problems of CAD systems in the thermal calculations are described. The authors presented the solution of these problems.

Currently, the work is continuing on the development of techniques to improve the simulation of the accuracy by reducing the error. On the results of further work are pinned great hopes, because they will allow to create an effective knowledge base. In turn, this knowledge base will significantly increase the reliability of REE, and also its workability. The result is the reduction in size of developed devices. A thorough study of temperature fields eliminates the types of active cooling where it is needed, even under conditions of relatively high temperature fields.

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